Nuclear Physics with MINERvA

Brian G. Tice

Department of Physics and Astronomy, Rutgers University, New Brunswick, New Jersey 08903 USA

On behalf of the MINERvA Collaboration[1]

Abstract. MINERvA is a precision neutrino experiment designed to improve our understanding of the neutrino-nucleus interaction. The experiment uses a fully active scintillation detector to allow full event reconstruction and includes nuclear targets helium, water, carbon, iron and lead. Here we describe the first steps in measuring lead to iron to carbon cross section ratios.

Keywords: neutrino interactions, neutrino-nucleus scattering, nuclear effects
PACS: 13.15+g; 25.30Pt; 95.55Vj

INTRODUCTION

MINERvA (**M**ain **IN**jector **E**xpe**R**iment for **ν-A**) is a compact, fully active neutrino detector designed to study neutrino-nucleus interactions with unprecedented detail [1]. The MINERvA detector is in the NuMI beamline at Fermi National Accelerator Laboratory and is positioned upstream of the MINOS near detector, which serves as a muon momentum spectrometer [2]. This fine-grained plastic scintillator detector is designed to study inclusive and exclusive neutrino interactions for both neutrinos and anti-neutrinos with energies of 1-20 GeV. The detector is equipped with an array of nuclear targets: helium, carbon, water, iron, lead. This range of nuclei enables MINERvA to measure the nuclear (A) dependence of neutrino interactions. Further details on MINERvA were presented at this workshop and can be found elsewhere [3].

MOTIVATION

The first physics goal for the nuclear program of MINERvA is to measure inclusive charged-current (CC) cross section ratios of iron to lead to plastic (CH) as a function of muon energy. This analysis will serve to demonstrate our ability to separate events according to the interaction nucleus, which will open the door to many nuclear physics topics.

Using the neutrino as a direct probe of the weak structure of the nucleon is complementary to using charged lepton probes, which are used to measure the electromagnetic structure of the nucleon. To this end, MINERvA will measure the CC quasi-elastic (QE) cross section of (anti-)neutrinos on each of its target nuclei. With these measurements, we can observe the nuclear dependence of the axial form factor of the nucleon. We

[1] http://minerva.fnal.gov

TABLE 1. Expected charged-current event rates for the amount of data recorded at the time of this presentation. These are the rates predicted by GENIE 2.6 [5] and are not corrected for detector efficiency or acceptance.

Target	Plastic	Helium	Carbon	Water	Iron	Lead
Fiducial Mass (tons)	6.43	0.25	0.17	0.39	0.97	0.98
ν_μ CC Events in 1.2e20 P.O.T.*	409k	16.8k	10.8k	24.4k	64.5k	68.4k

* MINERvA has been approved for 4.9e20 P.O.T. in low-energy mode and 12e20 P.O.T. in medium energy mode. After both beam modes, MINERvA will have seen 19M CC events in plastic.

can also learn about the interaction among nucleons in the nucleus by looking at the A-dependence of the contribution to the CCQE cross section from meson exchange currents.

Taking neutrino and antineutrino data enables MINERvA to be sensitive to the x-dependence of nuclear effects on F_2 and xF_3 through deep inelastic scattering (DIS). A CTEQ analysis of existing data suggests that the nuclear effects observed in neutrino DIS may differ in magnitude and shape from the effects seen with charged lepton probes [4].

Final state interactions (FSI) cloud the relationship between detector response and incoming neutrino energy. This complication is increasingly relevant as modern neutrino experiments use dense nuclear target materials, which have a greater chance for FSI. MINERvA will measure the A-dependence of FSI, including pion absorption and production in the interaction nucleus. These measurements will help experiments with the crucial tasks of translating their detector's observed final state to the neutrino interaction initial state and using visible energy to reconstruct the incoming neutrino energy. Studying FSI topologies also helps neutrino experiments better understand backgrounds to specific exclusive channels. An improved understanding of background processes which produce an electromagnetic final state will be particularly beneficial to neutrino oscillation experiments looking for ν_e appearance.

NUCLEAR TARGETS IN MINERVA

In addition to the active nuclear target of plastic scintillator (CH), MINERvA has passive nuclear targets of C, Fe and Pb; and we will soon be adding H_2O and He. These nuclear targets are relevant to many past, present and future neutrino experiments. The masses and expected charged-current event rates are shown in Table 1. A schematic of the nuclear target region is shown in Fig. 1. Carbon, iron and/or lead are combined to form each of the solid passive target modules. Lead and iron portions are carefully arranged to minimize systematic errors due to spatial dependence of acceptance and development of hadronic showers. There are either four or eight active scintillator planes separating the passive nuclear targets so that final state multiplicities and near-vertex activity can be measured and exclusive channels can be identified.

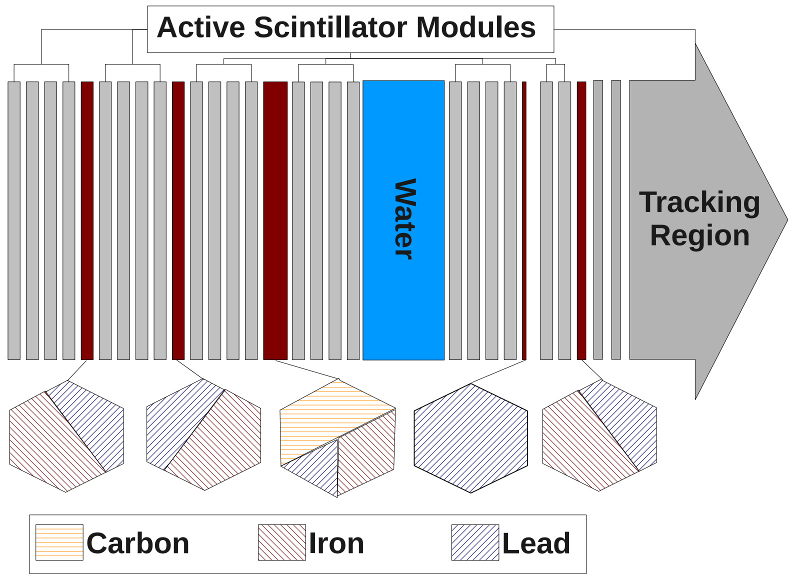

FIGURE 1. Schematic of the nuclear targets of MINERvA . Not shown is the liquid helium cryogenic vessel which sits just upstream (left) of the nuclear target region. The tracker region of the MINERvA detector is immediately downstream (right) of the nuclear target region. Currently, this analysis uses the rightmost target, which is composed of iron and lead.

INCLUSIVE ν_μ CHARGED-CURRENT RATIOS

Event Selection

In the analysis here, we only consider the most downstream passive nuclear target (lead/iron), which is the rightmost target in Fig. 1. This target is the easiest to analyze because it is immediately adjacent to the fully active tracking region of the detector, so the reconstruction does not need to track through passive material. The data being analyzed were obtained with the NuMI beam in the neutrino-tuned configuration [6].

The first requirement is that the event has a μ^-. Many muons produced in MINERvA exit the back of the detector and continue into the MINOS near detector, which serves as a muon spectrometer. To fully reconstruct these muons, MINERvA matches a reconstructed track in its detector with a reconstructed track in the MINOS near detector. The magnetized MINOS near detector provides charge identification for these muons. Currently, only these matched muons are used for analysis.

The second requirement is that the event vertex be in the vicinity of the nuclear target. The current definition of the event vertex is the reconstructed origin of the muon track. As a consequence, all vertices are in scintillator; none are in passive material, even if that is where the interaction occurred. Therefore we allow the vertex of the event to be in the first scintillator module downstream of the nuclear target. In the future, the other tracks in the event will be used to fit a vertex, which will allow for vertices in passive material. The transverse location of the vertex must be within an area defined by a hexagon of apothem 85cm.

We also require that there is no muon-like (minimum ionizing) activity in the region

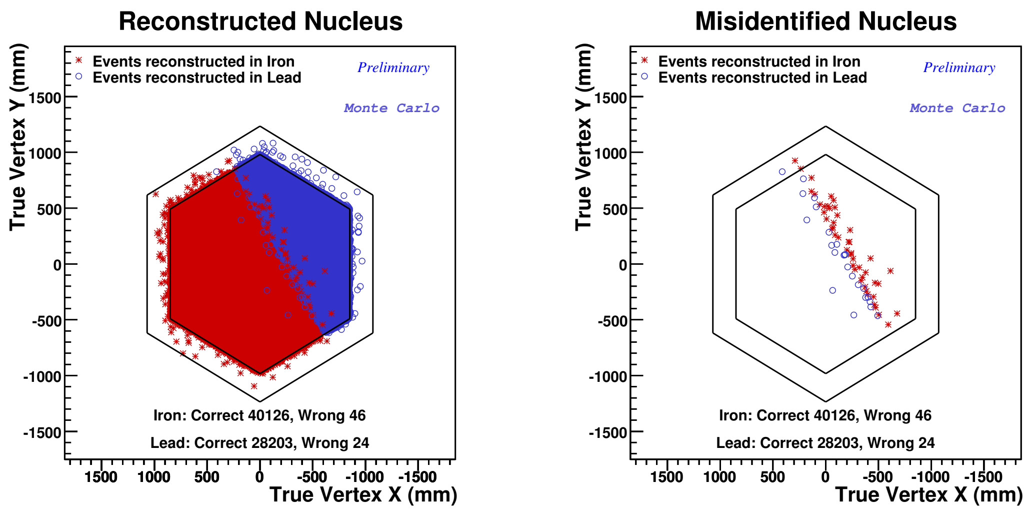

FIGURE 2. (Left) x:y-position of true vertex for events generated in the passive nuclear target. Red stars are events reconstructed in iron, and blue circles are events reconstructed in lead. Very few events cross the dividing line between lead and iron. (Right) The same plot drawn only for events which cross the dividing line between lead and iron. *Note*: These figures have been updated from the NuInt 2011 presentation and now include 10 times more simulated exposure. These figures also exclude events with a reconstructed vertex within 2.5cm of the line which divides iron from lead to increase the purity of identification of nucleus, which was not done for the NuInt 2011 presentation figure.

upstream of the vertex. This is an extra precaution to enforce the vertex requirement by minimizing the rare contamination from poorly reconstructed muons originating upstream of the nuclear target.

The events in the sample of charged-current events from the passive nuclear target are then broken into two groups: lead and iron. To identify the nucleus, the muon track is projected to the z-center of the target. The material that contains the (x,y) point of that intersection defines the nucleus of interaction. Misidentification of the nucleus due to the x:y vertex resolution is rare and is shown in Fig. 2. Figure 3 shows the reconstructed nucleus of interaction as a function of true z position of the vertex.

Analysis

It is important to point out that the selection of events from the lead and iron targets are currently lead-enriched and iron-enriched samples, since they have not had the scintillator contamination subtracted (see Fig. 3). This subtraction can be accomplished by utilizing events in scintillator elsewhere in the detector. To get a selection of such events in scintillator, we apply the same event selection described above to a region of four scintillator modules, which we call the "plastic reference target". We divide the plastic reference target into iron-like and lead-like regions to mimic the areas occupied by the passive nuclear target. Then the number of lead events is equal to the number of events in the lead-enriched sample minus the number of events in one module’s worth of

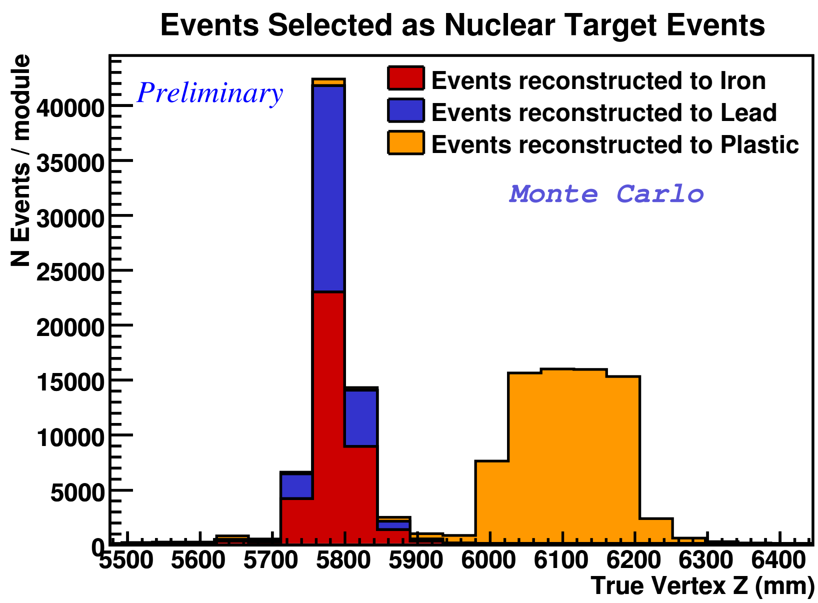

FIGURE 3. The z-position of true vertex for both the passive and active nuclear target event samples, binned by module and color-coded by reconstructed interaction nucleus. The largest bin, near $5775mm$, is the passive nuclear target. The next bin, near $5815mm$, is the first active module downstream of the passive nuclear target; this is the plastic contamination of the sample. The four high modules near $6000-6150mm$ represent the four modules of the plastic reference target. *Note*: This figure has been updated from the NuInt 2011 presentation now include 10 times more simulated exposure.

lead's plastic reference sample, with a correction for the z-dependent acceptance effect; see Equation (1).

$$N^{Lead}(E_\mu) = N^{Lead-Sample}(E_\mu) - N^{Plastic}(E_\mu) * zCorr(E_\mu) \tag{1}$$

Note that this estimates the plastic background using only events in plastic and therefore does not use a theoretical prediction comparing the cross sections of iron, lead and plastic.

We want to measure the ratio of the cross sections of lead to iron. To get a meaningful ratio, we want the only difference in the two samples to be the nucleus involved. However the iron and lead occupy different regions in x:y space, which introduces a systematic difference in the acceptance of muons due to detector geometry. To mitigate this effect, we again utilize the plastic reference target. The iron-like and lead-like regions of the plastic reference target differ only in their x:y space, so they can be used to cancel the effect. To compare the inclusive CC cross sections of lead and iron, we then use the double ratio in Equation (2), which corrects for the x:y acceptance difference. The final measurement of this ratio, and the evaluation of systematic uncertainties, is our ongoing effort.

$$Ratio_{Iron}^{Lead}(E_\mu) = \frac{\left(N^{Lead}(E_\mu)/N^{Lead-Ref}(E_\mu)\right)}{\left(N^{Iron}(E_\mu)/N^{Iron-Ref}(E_\mu)\right)} \tag{2}$$

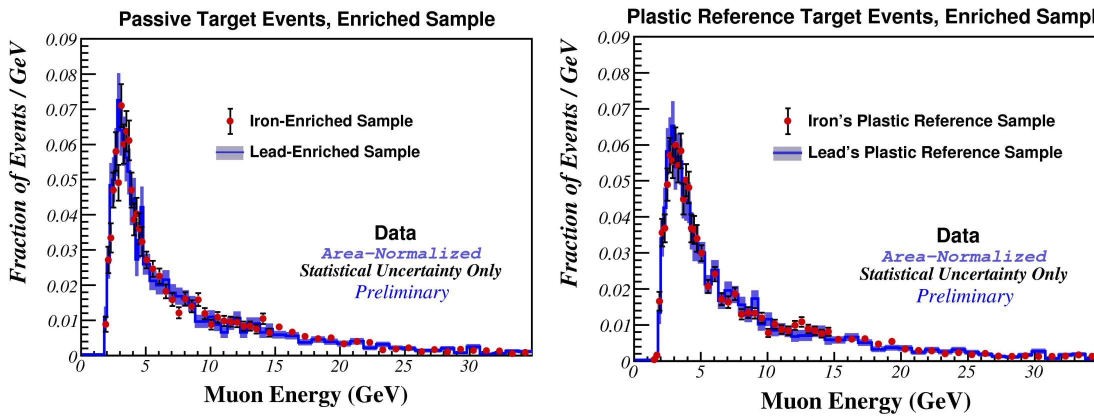

FIGURE 4. (Left) Reconstructed muon energy distributions from data for events in the passive target samples: iron-enriched (dot) and lead-enriched (line). Each histogram is area-normalized to 1. (Right) The same plot for the plastic reference target.

Figure 4 shows the muon energy distributions from data for events in the samples which will go into this double ratio.

ACKNOWLEDGMENTS

This work was supported by the Fermi National Accelerator Laboratory, which is operated by the Fermi Research Alliance, LLC, under contract No. DE-AC02-07CH11359, including the MINERvA construction project, with the United States Department of Energy. Construction support also was granted by the United States National Science Foundation under NSF Award PHY-0619727 and by the University of Rochester. Support for participating scientists was provided by NSF and DOE (USA) by CAPES and CNPq (Brazil), by CoNaCyT (Mexico), by CONICYT (Chile), by CONCYTEC, DGI-PUCP and IDI-UNI (Peru), and by Latin American Center for Physics (CLAF). Additional support came from Jeffress Memorial Trust (MK), and Research Corporation (EM). Finally, the authors are grateful to the staff of Fermilab for their contributions to this effort and to the MINOS collaboration for their efforts to operate the MINOS near detector and willingness to share its data.

REFERENCES

1. *The MINERvA Collaboration*, `http://minerva.fnal.gov` (2011).
2. *The MINOS Experiment and NuMI Beamline*, `http://www-numi.fnal.gov` (2011).
3. D. W. Schmitz, *The MINERvA Neutrino Scattering Experiment at Fermilab*, these proceedings (2011).
4. K. Kovařík, I. Schienbein, F. I. Olness, J. Y. Yu, C. Keppel, J. G. Morfín, J. F. Owens, and T. Stavreva, *Phys. Rev. Lett.* **106**, 122301 (2011).
5. *The GENIE Neutrino Event Generator*, `http://www.genie-mc.org` (2011).
6. M. T. Jerkins, *Measuring the NuMI Beam Flux for MINERvA*, these proceedings (2011).